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# Some Relationships between Aurora and Natural VLF and LF Noise at Plateau Station, Antarctica

by

Robert B. Flint, Jr.

February 1968

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**RADIOSCIENCE LABORATORY**

# STANFORD ELECTRONICS LABORATORIES

## STANFORD UNIVERSITY · STANFORD, CALIFORNIA

# SOME RELATIONSHIPS BETWEEN AURORA AND NATURAL VLF
# AND LF NOISE AT PLATEAU STATION, ANTARCTICA

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Prepared under

Radioscience Laboratory
Stanford Electronics Laboratories
Stanford University        Stanford, California

# ABSTRACT

Various relationships between aurora as observed in all-sky photographs and natural noise at frequencies of 1.5, 8, 50, and 110 kHz are found from data taken at Plateau Station, Antarctica, during the austral winter of 1966. The investigation is carried out in two parts: diurnal variations in occurrence are found for aurora and noise, and a minute-by-minute examination of relationships is made for a one-week period.

Diurnal occurrence of noise at 110 kHz peaks before magnetic midnight at about the same time as a peak occurs in the more familiar diurnal curves of occurrence of noise at 8 kHz and of aurora.

Examples are shown of several events in which associations between variations in noise and variations in auroral elevation, intensity, form, and rate of change can be found from detailed comparison of the data. Bursts of noise occasionally appear on the 110 kHz channel in the absence of noise on the other channels. Over the week as a whole, the average noise level correlates positively with auroral intensity at each of the noise frequencies. The average noise level is less following the main magnetic bay each night than before it. The majority of all noise changes during the week is found to coincide with changes in the aurora.

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## ACKNOWLEDGMENTS

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Chapter I

INTRODUCTION

## A. Plateau Station: Location and Experiments

Plateau Station, Antarctica, at 79°30'S, 40°15'E was set up in
December and January of 1965-6 as a joint project of the U.S. Navy Task
Force 43 and the Office of Antarctic Programs of the National Science
Foundation. The scientific activity planned for the station included
several geophysical projects as a part of a continuing program of geo-
physical investigation in the Antarctic. Phenomena on which data were
to be collected include the local magnetic field and its variations,
natural emissions and man-made signals in the very low frequency electro-
magnetic spectrum (0.3-30 kHz), natural emissions in the low frequency
spectrum (30-300 kHz), aurora, and cosmic noise absorption at 30 MHz.
This variety of data collected during the austral winter of 1966 has af-
forded an opportunity to verify and extend previous work on correlations
between geophysical phenomena. Some observations of the relationships
between natural emissions in the frequency range 1.0-110 kHz, and aurora
are presented in this report.

Being situated at a geomagnetic latitude of 77°, Plateau Station is
well suited to a correlation study. The locus of maximum auroral occur-
rence is an oval-shaped ring, fixed in space with the earth rotating be-
neath it. The long axis of the oval is oriented towards the sun and
extends from about 77° geomagnetic latitude on the dayside to about 67°
geomagnetic latitude on the nightside [Feldstein, 1966; Hartz and Brice,
1967]. Thus Plateau Station is on the auroral oval at noon and is about
10° inside the oval at midnight. At the high geographic latitude of the
station, the sun is below the horizon continuously for a four-month dark
period and below the horizon for a part of each day for two months pre-
ceding and two months following the dark period. The skies over the
high interior plateau of the Antarctic continent are almost constantly
clear, facilitating photography and measurement of auroral activity.

Very low frequency receiving equipment has been part of the instrumentation of several of the Antarctic Stations for a number of years, and several reports have described relationships between natural VLF noise (0.3-30 kHz) and aurora [Martin et al, 1960; Morozumi, 1962, 1963; Helms and Turtle, 1964; Morozumi and Helliwell, 1966]. At Plateau Station the inclusion of a low frequency (30-300 kHz) receiving system in addition to the VLF system has afforded an opportunity to extend the investigation of aurora-noise relationships to include LF as well as VLF emissions.

While the use of cosmic noise absorption data would have been useful in the investigation, instrumentation difficulties prevented the collection of good data during the dark period.

## B.    Previous Work

In this report no attempt is made to review previous work in detail. However, a brief note on some of the past correlation studies of aurora and VLF-LF noise (0.3-300 kHz) is useful in identifying those aspects of the Plateau Station data which confirm or extend previous findings.

Compared to the amount of literature on either VLF noise or aurora studied separately, few studies have been made of the relationships between the two phenomena. Statistical association was found between subvisual aurora and hiss outside of the auroral zone by Duncan and Ellis [1959]. Correlation of occurrences of aurora and hiss and similarities between their diurnal variations were found at Byrd Station in the auroral zone by Martin, Helliwell, and Marks [1960].

One-to-one association between aurora and noise was found by simultaneous aural observations of noise and visual observations of aurora in Greenland by Jørgensen and Ungstrup [1962].

Close association between hiss and auroral arcs and bands around magnetic midnight at South Pole Station was reported by Morozumi [1962, 1963]. Statistical association, but no detailed relationship was found between aurora and noise near magnetic noon.

A correlation of aurora and noise with one another and with magnetic activity both on a day-to-day and, for certain events, on a minute-to-

minute basis was found by Helms and Turtle [ 1964 ]. They reported that the maximum of auroral intensity always coincides with decaying hiss.

Ungstrup [1964] notes a relationship between chorus-like emissions and low level, flickering aurora.

In the diurnal occurrence of aurora and VLF noise, the time of maximum occurrence of aurora is found to follow that of noise at Tromso in the auroral zone by Harang and Larsen [1965]. They also find a positive correlation between hiss and absorption for small values of absorption, but a negative correlation for larger values of absorption, indicating perhaps why some bright auroral displays do not correlate well with noise.

Using a crossed loop receiving system, Harang and Hauge [1965] find no preferred direction of arrival for hiss associated with auroral displays, indicating sources at close ranges.

Morozumi and Helliwell [1966] show that the sequence of geophysical events in the auroral zone can be divided into well-defined phases, occurring before auroral breakup, during breakup, following breakup, and during the magnetic daytime hours, respectively. Each phase is characterized by certain types of activity in the aurora, in VLF noise, in magnetic activity, and in ionospheric absorption.

Hartz and Brice [1967] investigate the temporal and latitudinal variations of a wide variety of geophysical phenomena. They suggest that two different types of particle precipitations are related to two distinct categories of activity. In the present paper, all closely related auroral and noise events are evidently associated with what they call the "splash" type of precipitation.

In general, the development of knowledge of the relationships between natural noise and aurora has been limited to noise in the VLF frequency range (0.3-30 kHz). Helms and Turtle [1964] note that aurora-associated hiss extends above 40 kHz and Dowden [1959] suggests that the origin of noise at 100 kHz is in the aurora. The other papers cited above have dealt only with noise below 30 kHz.

## C. Contributions of This Paper

In previous papers detailed comparison of aurora and natural noise with time resolution of the order of minutes has been limited to the times surrounding major bursts of activity. For this paper aurora and noise were scaled and compared at one minute intervals throughout an entire week which was selected on the basis of good equipment operation and clear aurora. The results show that many types of relationships are possible between noise and aurora and that most noise bursts are related to some characteristic of the aurora.

In this report the relationship to aurora of noise at LF frequencies of 50 kHz and 110 kHz is studied in addition to noise in the VLF range at frequencies of 1.5 kHz and 8 kHz. Hiss at the LF frequencies of 50 and 110 kHz is found to behave in much the same way as the more familiar VLF hiss. However, bursts of noise appearing on the 100 kHz channel in the absence of noise on the low frequency channels are found, and these bursts frequently correlate with aurora.

## Chapter II

## MEASUREMENT TECHNIQUES

### A.   Noise Equipment

The VLF and LF systems consisted of antennas, several stages of amplification, filters, detectors, a chart recorder, tape recorder, and timing equipment.  For circuit design reasons, the spectrum was divided between two broadband systems, having frequency ranges of 0.3 kHz to about 20 kHz and 20 kHz to 120 kHz, respectively.  Each system had a separate antenna, an IGY delta type 30 feet high and 60 feet across the base, oriented perpendicular to the magnetic meridian.  To reduce interference from the station, the low frequency antenna and preamplifier were located 2000 feet away, while the high frequency system, not requiring such isolation, was located 500 feet away.

Fixed frequency narrow band filters were used to sample portions of the broadband spectrum in each system.  The output of each filter was detected and integrated.  A slow-charge fast-discharge integrator was used to discriminate against impulsive activity such as sferics.

Amplitude calibration of the various bands was accomplished by inserting a known current at the center frequency of each filter in a separate calibration loop that was magnetically coupled to the antenna loop.  From the equivalent noise bandwidths of the various filters, the pen deflection on the chart recorder could be calibrated in watts/$m^2$Hz for each channel.  Unfortunately, the calibration system did not operate properly in the LF receiver so that these bands are not calibrated absolutely.

The chart was normally run at a speed of either 2.5 mm/min or 1.0 mm/min, allowing resolution of events spaced at 12 sec or 30 sec, respectively.  Time marks were placed on the edge of the chart at one minute intervals, with accuracy within one sec.

Full scale deflection on the charts was adjusted for each channel to keep most of the activity on scale and at the same time to show as much detail in low level activity as possible.  Minus three dB points,

noise bandwidths, and full scale calibration values for each channel are given in Table 1.

Table 1

FILTER FREQUENCIES, -3dB POINTS, NOISE BANDWIDTHS,
AND CALIBRATION CONSTANTS

| Filter Frequency (kHz) | -3 dB Points (kHz) | Noise Bandwidth (kHz) | Full Scale (Watts/$m^2$/Hz) |
|---|---|---|---|
| 1.5 | 0.9, 2.1 | 1.6 | $5.7 \times 10^{-16}$ |
| 8 | 7.2, 8.4 | 1.6 | $2.2 \times 10^{-16}$ |
| 50 | 51 , 54 | 5.5 | not calibrated |
| 110 | 98 128 | 38 | absolutely |

A photograph of a typical chart is shown in Fig. 1. From top to bottom, the eight channels are: the output of a zenith photometer with a 5577A° filter, the outputs of five channels of natural noise at frequencies of 110, 50, 8, 2.5, and 1.5 kHz, and the outputs of micropulsation and magnetic field measurement equipment. The gain of the noise channel at 2.5 kHz is high in order to study the daytime chorus-type activity, and therefore this channel is not used in this report. The full scale deflection on the micropulsation at 0000 UT is a calibration. The photometer, micropulsations, and magnetometer are turned off for about 15 minutes at 0300 UT due to interference from a local transmitter.

A tape recorder was used to sample broadband signals from the VLF system for 2 minutes each hour.

B. Aurora Equipment

An IGY-type all-sky camera was used to photograph the aurora. This device employs a convex mirror to photograph the entire sky on a single frame of 16mm film. The time is also recorded on each frame. Twenty-second exposures were made starting each minute, except every fifteen minutes when a five-second exposure and a seventy-second exposure were made to show very bright and very dim aurora respectively. Kodak Tri-X negative film was used.
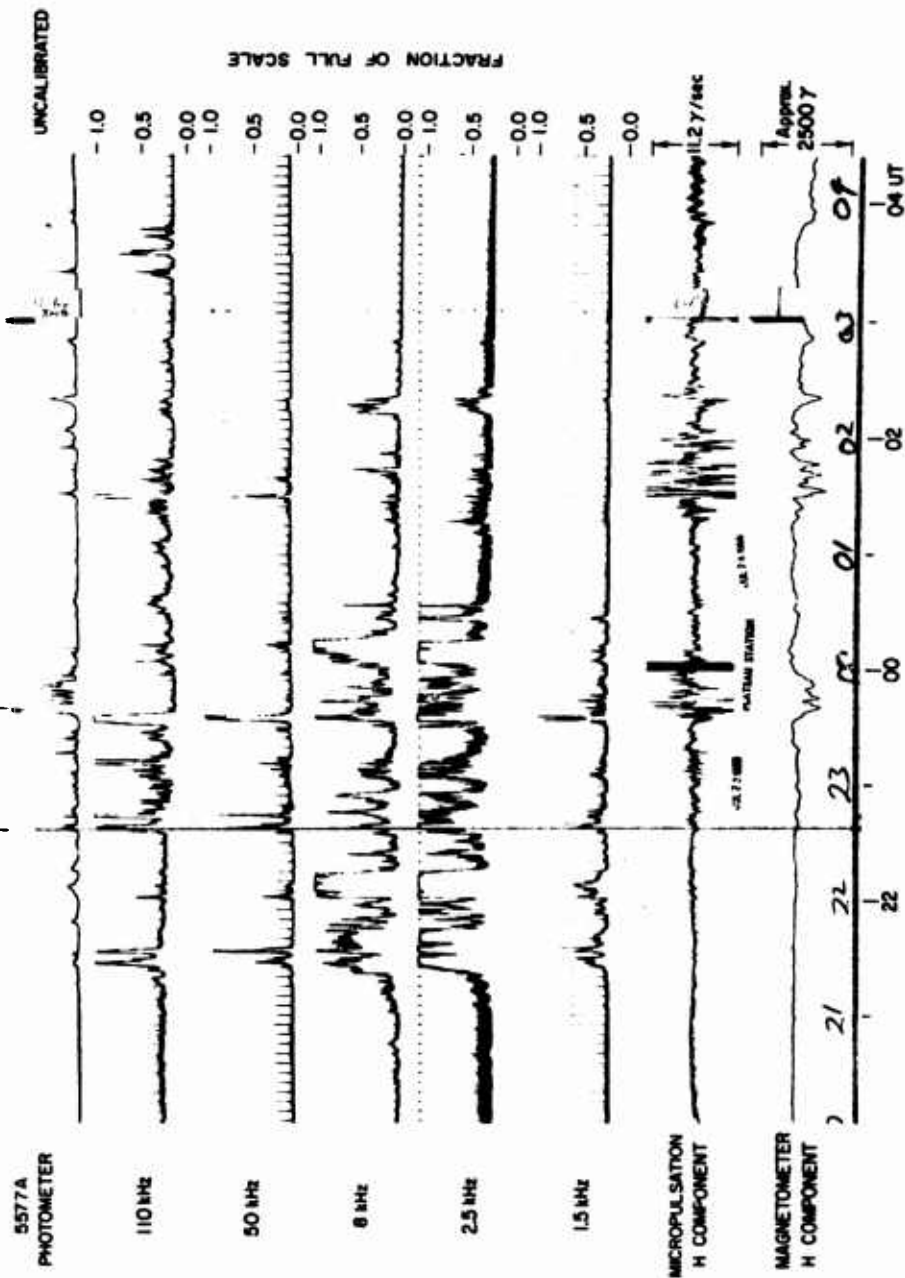
Fig. 1. SAMPLE OF CHART OF NATURAL NOISE DATA AND RELATED GEOPHYSICAL PHENOMENA, PLATEAU, 23 JULY 1966, 2000 UT TO 24 JULY 0400 UT.

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## C.   Magnetic Equipment

The magnetic north-south component ($\underline{H}$ component) of the magnetic field and its variations were measured by a fluxgate magnetometer and micropulsation receiving equipment. The magnetometer responds to magnetic variations in the range 0-1 Hz. The micropulsation system employs multi-turn loops seven feet across to detect magnetic variations up to about 3 Hz. The outputs of the magnetometer and micropulsation equipment appear on the bottom two channels in Fig. 1.

## Chapter III

## DATA REDUCTION

### A.    Scaling of Noise for Diurnal Occurrence Curve

Twenty winter days having a value $\Sigma K_p \leq 9$ were selected as a sample of quiet magnetic conditions.  Twenty days on which $16 \leq \Sigma K_p \leq 27$ were selected as a sample of moderate geomagnetic acitivity, and twelve days with $\Sigma K_p \geq 28$ were taken as a sample of high activity.

During each hour of each day selected, occurrence or non-occurrence of natural noise above the equipment noise level was noted for each filtered band.  The diurnal variation of the percentage of time that natural noise was detected was plotted for each of the filtered bands.  While such scaling is, of course, dependent upon the equipment noise level, when noise was detectable it was generally well above the equipment noise level.

### B.    Scaling of Aurora for Diurnal Occurrence Curve

All-sky camera photographs were scanned for occurrence of non-occurrence of aurora during each hour of the day, and the percentage occurrence of aurora was found by the same method used for noise occurrence.  However, data contaminated by twilight or sunlight toward the end of winter were omitted in the averaging.

The number of very active days during the dark periods was insufficient to determine a diurnal variation of auroral occurrence, but on the basis of auroral behavior on the few very active days that did occur and from indications in the noise, it is probable that such a plot would show auroral activity during every hour of every active day.

### C.    Scaling of Noise for High Time Resolution Study

For the minute-by-minute comparison of aurora and noise, auroral photographs and noise data collected during the week of July 21-28, 1966 were scaled at intervals of one minute.  This week was chosen for good

equipment operation and minimal twilight and moonlight interference   The sun was always more than 9° below the horizon.  The moon was below the horizon most of the time and was never more than 30° above it.

Noise amplitudes were scaled directly from the chart in scale divisions.  When noise changed significantly over a one-minute interval, the peak value was read, since the noise statistics were intended for comparison with auroral data and the all-sky camera tends to be a peak-reading instrument.  Noise occasionally went off scale on the charts.  Amplitude could be estimated to about 110 percent of full scale.  When the signal went beyond that point, values were read as 110 percent full scale.  Off-scale points can be easily recognized by the flat top to the traces as illustrated in Fig. 1.

### D.  Scaling of Aurora for High Time Resolution Study

Each frame of the all-sky photographs was scaled for activity, structure, form, and intensity according to a classification system identical in most respects to the IUGG classification code [International Union of Geodesy and Geophysics, 1963].  In the present study attention is concentrated on the variations of activity, form, and intensity.  Auroral activity was rated on a subjective scale ranging from 1 (low activity) to 3 (high activity).  In determining this number, rate of travel across the sky and rate of brightening or fading of the aurora was considered.  Because of the difficulty in determining the details of motion of the aurora from the photographs, this index involves a slight departure from the IUGG convention, in which each activity number refers to a given form of auroral activity.

Auroral intensity was rated on a subjective scale ranging from 0 (sub-visual) to 4 (comparable to full moon).  The elevation of the aurora above the horizon was also recorded.  When two or more forms appear on the same frame, the coded description was based on the form having the highest elevation or largest intensity or activity number.  The principal utility of subjective activity and intensity numbers in this study is in the timing of changes, rather than in any physical significance in

the numbers per se.  A motion picture projector facilitated consideration of each frame of the aurora film in the context of the frames surrounding it.

Data from an auroral photometer pointed toward zenith was available (see Fig. 1).  However, the subjective intensity numbers were used in this study since the zenith photometer does not indicate aurora near the horizon.

## E.  Magnetics

The start times of the main magnetic bays and micropulsation bursts were noted as indicators of local magnetic activity.  Such bursts are usually impulsive and start times can be determined with an uncertainty of less than two minutes.

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Chapter IV

RESULTS

## A.    Diurnal Variations of Occurrence of Natural Noise and Aurora

The diurnal variations of occurrence of natural noise and aurora are plotted in Fig. 2.  Magnetic midnight and magnetic noon are indicated. At Plateau Station magnetic midnight occurs at 0048 UT.  Local noon, when the auroral data are subject to the greatest interference from twilight, is also indicated.  The first eight hours on the left hand side of the plot are repeated on the right hand side to show clearly the variations around magnetic midnight.

Two distinctly different types of natural noise contribute to the diurnal variations.  In the minute-by-minute comparison of noise and aurora, auroral-type hiss is of primary interest.  This type of noise is impulsive; large amplitude variations may occur within seconds [Helliwell, 1965].  Bursts of this type cover a wide band of frequencies and noise may be found anywhere from 1 kHz or so up to an undetermined top frequency above 100 kHz.  Auroral hiss is characteristic of local magnetic night hours, though bursts of this type of activity may also occur throughout the day when magnetic conditions are active.  It is always non-discrete, being made up of band limited white noise rather than of individual tones. This noise is associated with what is called the "splash" type of precipitation by Hartz and Brice [1967].

The second type of noise is a daytime type.  It characteristically begins and ends relatively slowly, varying only a few dB in a minute.  It generally occurs below 4 kHz and is never seen on the filtered channels at 8 kHz or above.  It may include discrete tones (chorus) or non-discrete noise in the form of low frequency hiss or "polar chorus" [Ungstrup and Jackerott, 1963].  This type of noise is associated with what is called the "drizzle" type of precipitation by Hartz and Brice [1967].

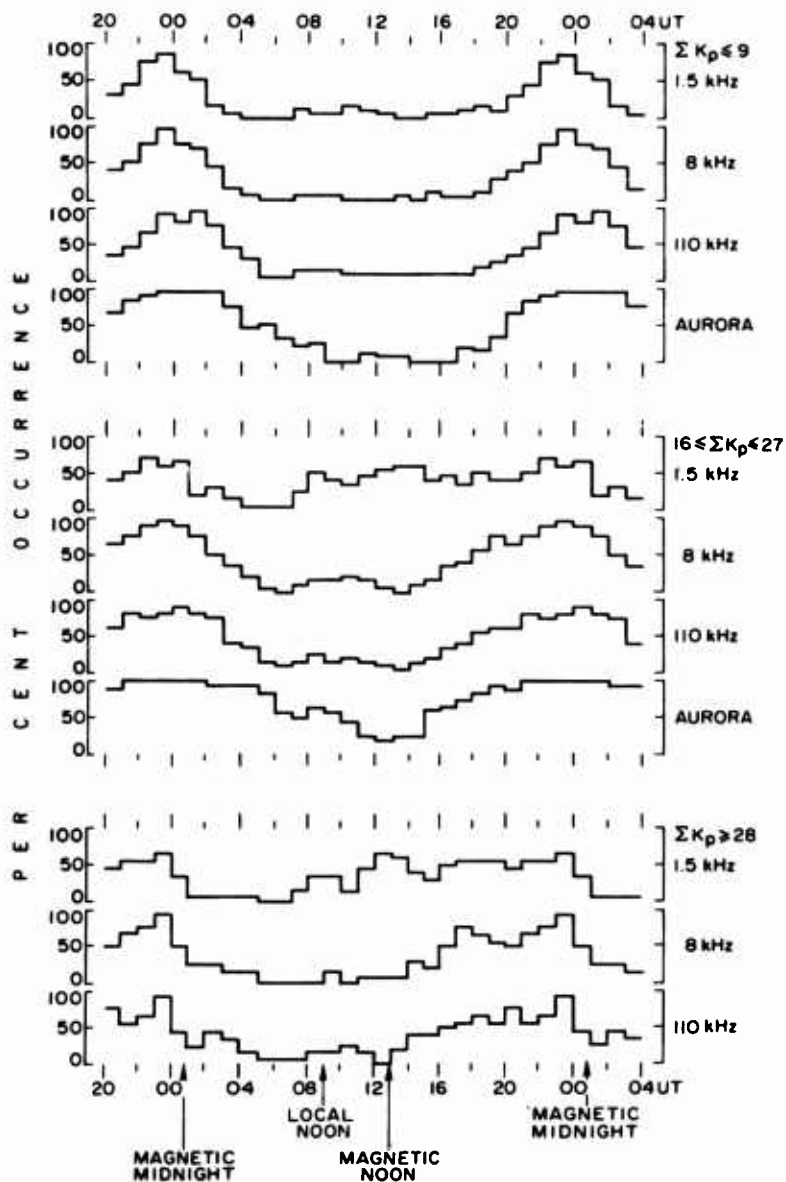Observations of the diurnal variations of natural noise and aurora are listed below.

Fig. 2. DIURNAL OCCURRENCE OF NOISE AND AURORA.
The aurora curve for very active magnetic contains
has been omitted due to insufficient data.

(1) The most obvious feature of all the curves in Fig. 2 is maximum of occurrence of the three noise frequencies and of aurora centered about 2300-0000 UT. The peak in auroral occurrence extends longer after midnight than does noise occurrence.

(2) In the case of active magnetic conditions, noise occurrence drops off rapidly following magnetic midnight. From data collected at other stations, it is known that high absorption is associated with such magnetic activity and probably accounts for the occurrence decrease [Harang and Larsen, 1965; Morozumi and Helliwell, 1966].

(3) For all magnetic conditions, activity on the 1.5 kHz noise band falls off more rapidly than on the higher frequencies following the midnight peak.

(4) A minimum in noise occurrence occurs at 0500-0700 UT.

(5) A small secondary peak in auroral-type hiss occurrence appears at 0800-1000 UT. Hiss at this time is usually in the form of couple of isolated short bursts of noise, frequently accompanied by a small, fast-moving band of aurora. Both this peak and the peak before magnetic midnight, roughly agree in magnetic time with peaks of the mean intensity of 5577Å night sky emission for the southern hemisphere found by Sandford [1964]. The midnight peak agrees in magnetic time with that found by Jørgensen [1966] for auroral hiss.

(6) There is a maximum of activity on 1.5 kHz at 1000-1500 UT. This maximum is greater for higher magnetic activity. Activity at this time is chorus or daytime type non-auroral hiss.

(7) Daytime activity of noise and aurora depends directly upon magnetic activity, although the occurrence of activity in the hours before midnight is nearly 100 percent regardless of magnetic conditions.

(8) Auroral and noise activity building up to the midnight peak begins earlier for more active magnetic conditions.


B.    Observations From High Time Resolution Study

In order to investigate qualitative relationships between noise and aurora, the following quantities were plotted on the same time scale: noise amplitude at each of four frequencies, auroral elevation, auroral intensity, auroral activity index, and a one or two word description of the auroral form. Figure 3 is an example of such a plot. The approximate levels of equipment and man-made noise are indicated on each of the

noise channels by a dotted line. These levels are established by mea-
suring the noise at quiet times of day. Plots of this type were made for
all periods of noise activity during the week of July 21-28.

The period covered by the noise chart shown in Fig. 1 includes the
entire active part of the night of July 23-24. At about 2340 UT and
again at 0130 UT there are nighttime magnetic bays and micropulsation
activity. Before the first bay, starting about 2100 there is consider-
able activity on all noise frequencies. Following the first magnetic
bay, there is less overall noise activity and following the second bay
there are only a few isolated bursts of noise. Activity ends about 0100
in a burst which appears on the 110 kHz channel but not on any of the
lower frequencies. Three sections of the aurora-noise plot corresponding
to sections of Fig. 1 are shown in the following sections of the report.
Examples of activity before the bays, during a bay, and during a "100 kHz
event," respectively, are described. In addition, an example of a day-
time burst of hiss and aurora is given. Finally, as a different presen-
tation of similar noise data, the frequency spectra are sketched at
intervals for an hour during hiss and auroral activity.

### 1.   Pre Magnetic Bay Activity

The most complex interrelations between aurora and noise take
place in the period preceding the magnetic bay. Figure 3 is an example
of a section of an aurora-noise plot for this time. Several features
are apparent despite the complexity of the activity. Two bursts of
auroral and noise activity begin about 2123 and 2200 respectively (all
times given are in UT). An almost simultaneous peak of all noise and
auroral parameters occurs at 2126-27. The noise minimum at 2130 cor-
responds to a change of form and a minimum in intensity of the aurora.
The broad peak in 8 kHz noise at 2200-14 is preceded by auroral patches
and is followed by patches, while only bands are present during the
peak. The small peak in 8 kHz noise at 2222-26 corresponds to the
presence of an auroral band.

More details of the relationships between the aurora and noise
in Fig. 3 can be found from a minute-by-minute inspection. Selected all-

sky photographs corresponding to the period shown in Fig. 3 are shown in
Figs. 4 and 5.

In these and all other all-sky photographs in this report, the
image has been reversed to place east to the right of north. (When one
looks skyward, east is to the left of north.) The cross of lights in the
illustrations is in the geographic north-south and east-west axes. Lights
are placed at 8° intervals of elevation. Geomagnetic north is indicated
by $N_m$ in Fig. 5. The light which appears on the southwest horizon in
some of the photographs (e.g., 2111 in Fig. 4) is a search light on the
station. The spot which appears off the southeast edge of some of the
photographs (e.g., 2111 in Fig. 4) is a marker which appears every
fifteen minutes.

A minute-by-minute description of activity in Figs. 3, 4, and
5, follows:

| | |
|---|---|
| 2110 | (time in UT) Previous to this time there has been a little faint aurora and a slight amount of noise, but no major activity. A faint band of aurora is on the eastern horizon. |
| 2110-14 | The aurora moves slowly toward the station and becomes brighter. |
| 2115 | Auroral intensity decreases slightly as a faint band of aurora nears the zenith. |
| 2116 | Auroral activity, intensity, elevation, and noise at 8 and 110 kHz all increase. |
| 2117 | Noise at 8 kHz reaches a small local peak about 5 dB over the level at 2115. |
| 2118 | Noise at 110 kHz and auroral intensity reach small local peaks. The aurora moves a few degrees away from zenith. The noise at 8 kHz is at a local minimum. |
| 2121-24 | A short bright band forms in the northeast as 110 kHz noise slowly increases. Noise at 8 kHz rises 10 dB over its level at 2118. |
| 2124-27 | The auroral band becomes active and appears to be a "source" for a fainter band, which crosses to the southeast and then sweeps overhead, becoming brighter. Noise on all frequencies rises sharply, |
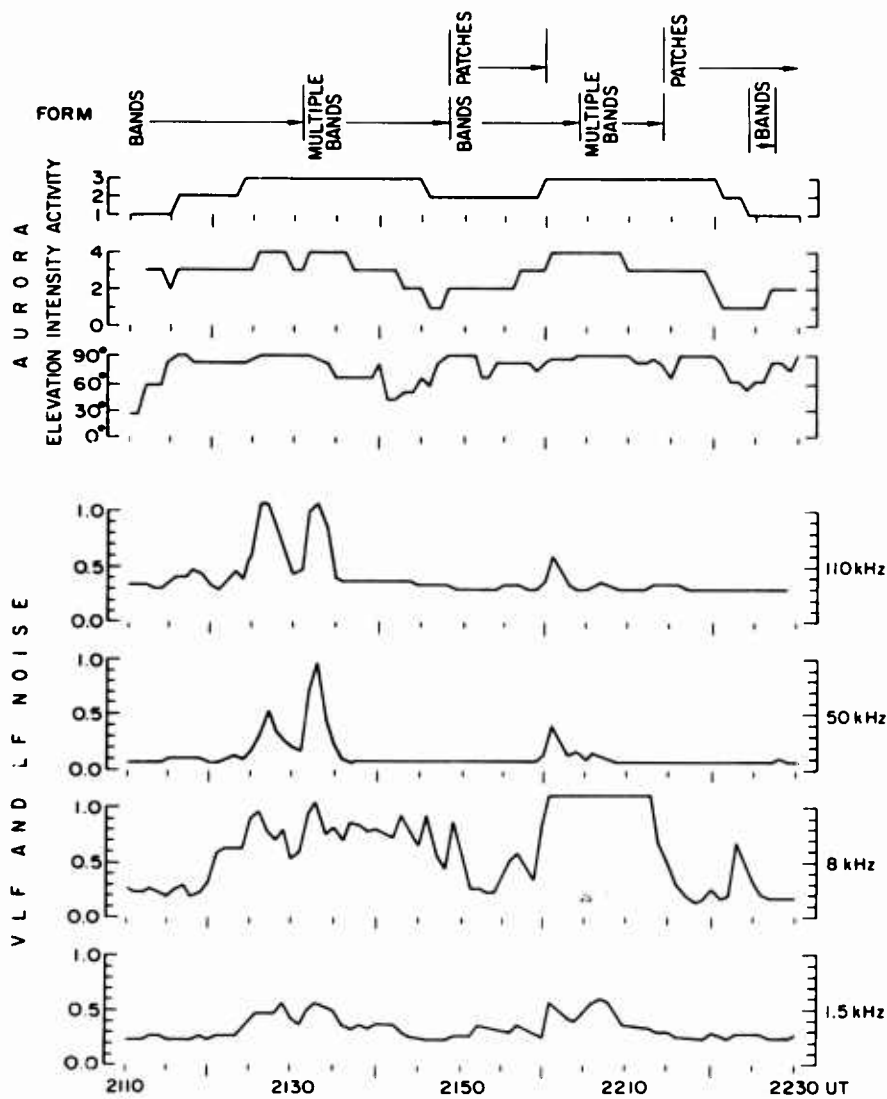
Fig. 3. NIGHTTIME EVENT BEFORE MAGNETIC BAY, PLATEAU, 23 JULY
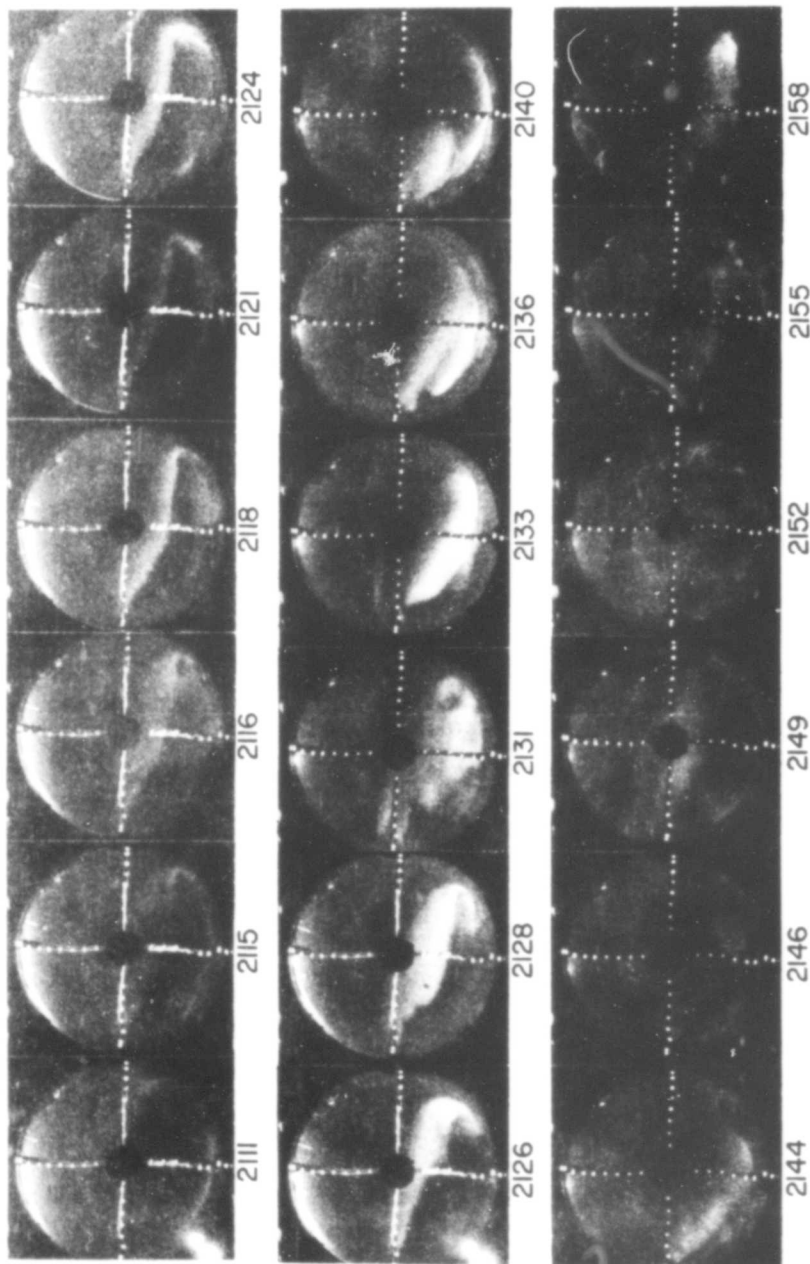1966, 2110-2230 UT.

Fig. 4.  SELECTED ALL-SKY PHOTOGRAPHS FOR FIG. 3, PART 1.
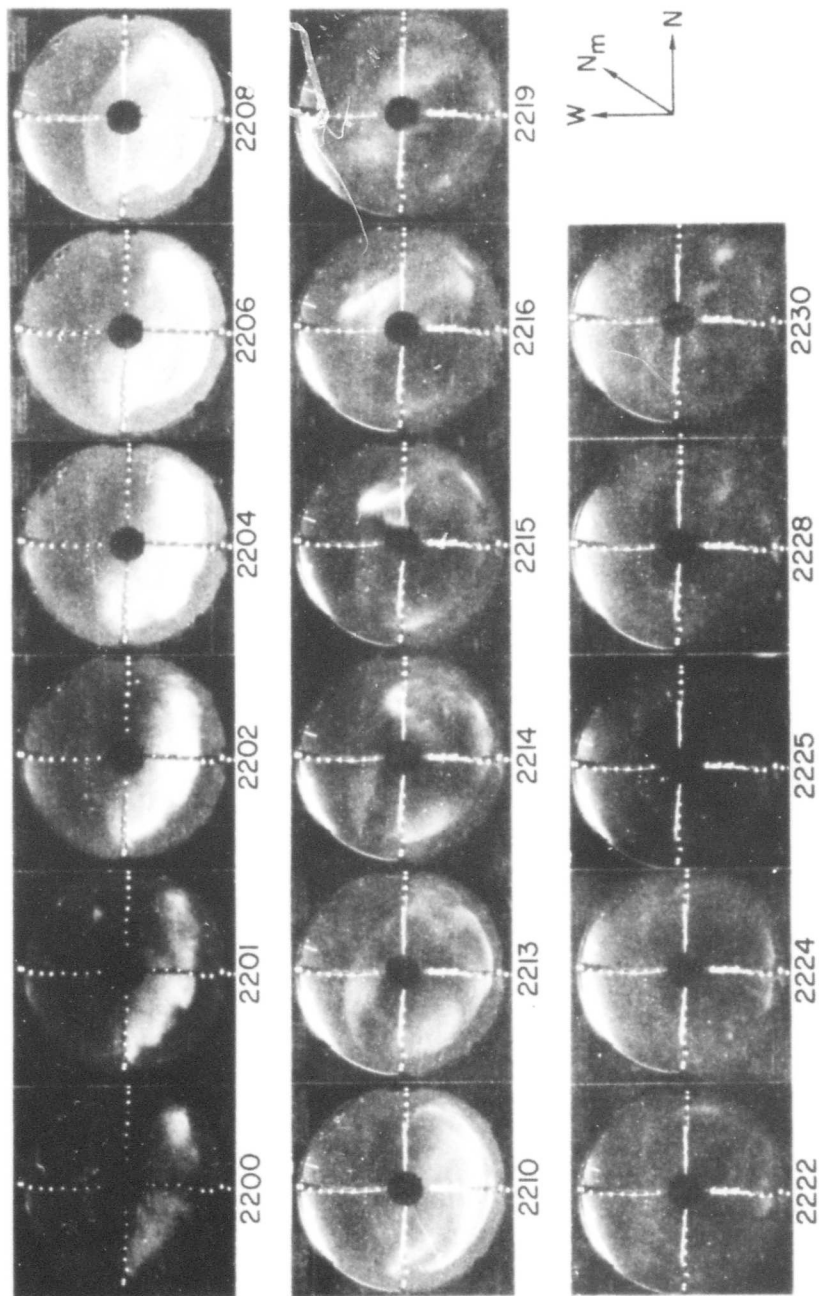
Fig. 5. SELECTED ALL-SKY PHOTOGRAPHS FOR FIG. 3, PART 2.

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peaking first on 8 kHz (4 dB over level at 2124) and then on 50 kHz at 2127.

2128    The amplitude of the three upper noise frequencies has decreased. Aurora has spread to its greatest horizontal extent.

2129    Noise at 1.5 kHz peaks and 8 kHz noise reaches a second peak 1.7 dB less than the first peak.

2130-31    At all frequencies the noise is at a local minimum. Noise levels at 110 kHz and at 50 kHz are down 18 and 10 dB respectively from their peak values, and noise levels at 8 kHz and 1.5 kHz are each down 6 dB from peak values. Auroral intensity also decreases and the auroral band breaks into multiple bands.

2133    The auroral band reforms and brightens a few degrees away from zenith. Noise reaches a peak on all frequencies simultaneously. The peaks are at about the same level as the previous peaks except for the 50 kHz peak which is 6 dB greater.

2133-36    The aurora remains bright, but the center of the band moves back towards the east. Noise decreases very rapidly.

2136    Noise intensities at 110 and 50 kHz are down almost to their background noise levels. Noise at 8 kHz is down 3 dB and noise at 1.5 kHz is down 7 dB from peak values.

2136-40    Wispy patches of low intensity aurora (barely visible) move rapidly near the zenith as the main band fades and moves away. Scaled elevation does not indicate the activity very well at this time because of the presence of two types of activity in the sky.

2140-55    The aurora is fainter but still active. Noise at 8 kHz has peaks almost as high as previous peaks correlating with bright aurora. One-to-one correlation cannot be found for each of the 8 kHz noise peaks, but the peak at 2149 does coincide with the arrival of a dim patch in the zenith.

2155-57    A patch of aurora in the northeast becomes brighter as 8 kHz noise increases by 9 dB between 2153 and 2157.

2159-2201    Noise at all frequencies suddenly increases at the same time that an increase of auroral activity and intensity occurs. Bands rather than patches become dominant.

2201-04      Noise at 50 and 110 kHz quickly decreases. The aurora spreads horizontally in the eastern sky and becomes brighter.

2204-06      The auroral band breaks into multiple bands and spreads further about the sky in very active forms.

2207-08      There is a small secondary peak on 50 and 110 kHz and a peak on 1.5 kHz. The 8 kHz channel is off scale. The aurora remains very active and spreads across zenith to the west.

2209-10      Auroral intensity falls off at the same time that 1.5 kHz noise decreases by 9 dB from its peak value.

2213-17      As 8 kHz noise drops (over 20 dB down altogether), the auroral bands fade, leaving only a small patch which moves rapidly across the sky.

2217-22      The auroral forms become fainter, move away, and become less active.

2223-26      A noise peak of about 15 dB occurs on the 8 kHz channel only. A small auroral band in the east reaches maximum intensity at 2224.

2226-30      There is no significant noise, but active thin patches of aurora remain.

In both of the two broad periods of activity, beginning at 2124 and 2200 respectively, high auroral activity (activity = 3) begins as the noise rises but extends well after the noise decreases again. It has been suggested that noise and aurora are caused by the same particle precipitation, but that the precipitation also creates absorption which reduces the noise shortly after it starts [Harang and Larsen, 1965]. A broad peak on the 8 kHz noise between 2201 and 2213 coincides with aurora which at times is quite faint. The coincidence of weak aurora and noise on the 8 kHz band in the absence of noise on the other noise bands was observed several times during the week of July 21-28.

## 2. Magnetic Bay Event

In Fig. 1 the dominantly active parts of the nighttime period are the times surrounding the magnetic bays at 2340 and at 0130. All channels in Fig. 1 appears to be affected nearly simultaneously. In order to illustrate this type of event in greater detail, the plot of auroral parameters and noise amplitudes for the first bay event is shown in Fig. 6. The magnetometer trace is included to show the time relationship of auroral and noise activity at the beginning and bottom of the bay. The auroral activity number is omitted since it was scaled at constant level 3 throughout the period. Selected all-sky photographs of the period are shown in Fig. 7.

Noise and auroral intensity rise several minutes before the aurora reaches zenith. When the aurora moves overhead, the noise decreases, presumably due to absorption. The time of maximum noise corresponds to the maximum light intensity of the narrow auroral band just before it breaks into multiple bands.

A minute-by-minute description of the magnetic bay event follows:

| | |
|---|---|
| 2320-28 | Much auroral activity is present with considerable movement, fading, and reappearing of bands. |
| 2328-30 | The aurora dims and moves toward the northwestern horizon. Noise at 50 and 110 kHz decreases by 10 and 5 dB respectively. |
| 2330-31 | Noise on all frequencies begins to increase. |
| 2333 | Multiple bands of aurora are overwhelmed by a single narrow bright band at $50°$ elevation. The magnetic field begins to decrease as the band becomes extremely bright. |
| 2335 | The aurora begins to move toward zenith. Noise on the VLF bands at 1.5 and 8 kHz reaches a peak (noise at 110 and 50 kHz is off scale). The auroral band is at maximum intensity. |
| 2336 | The auroral band breaks into multiple bands and covers much of the sky. The noise begins to decrease. |
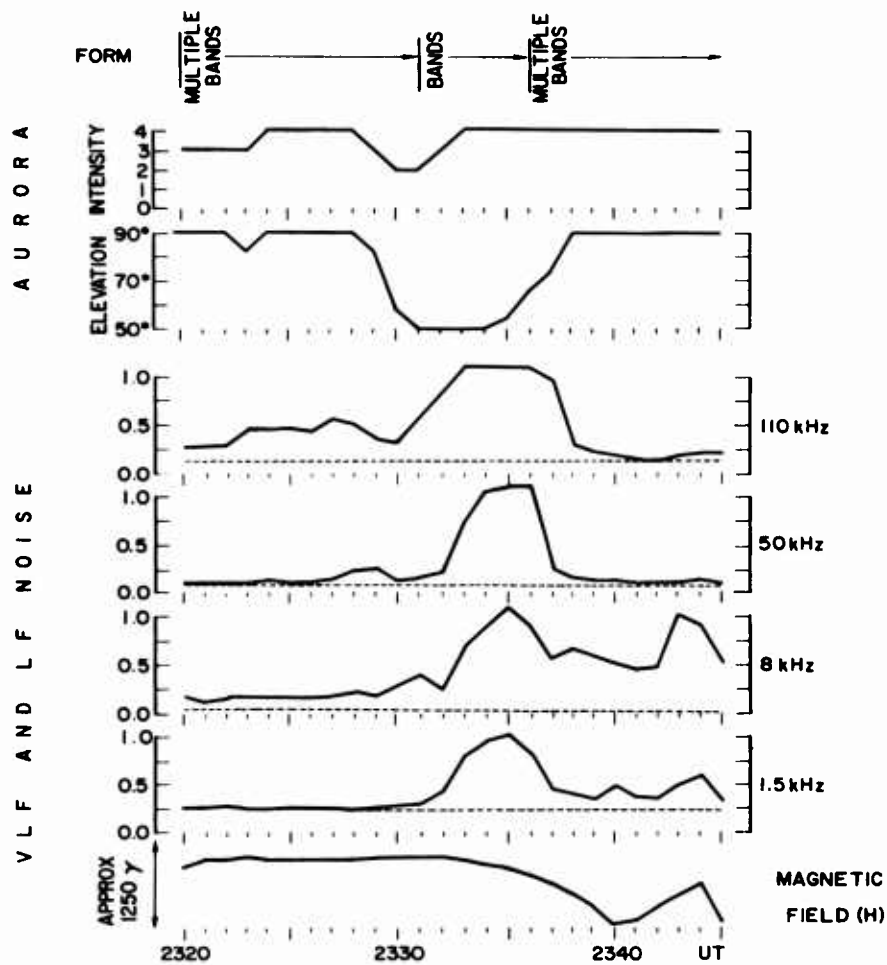
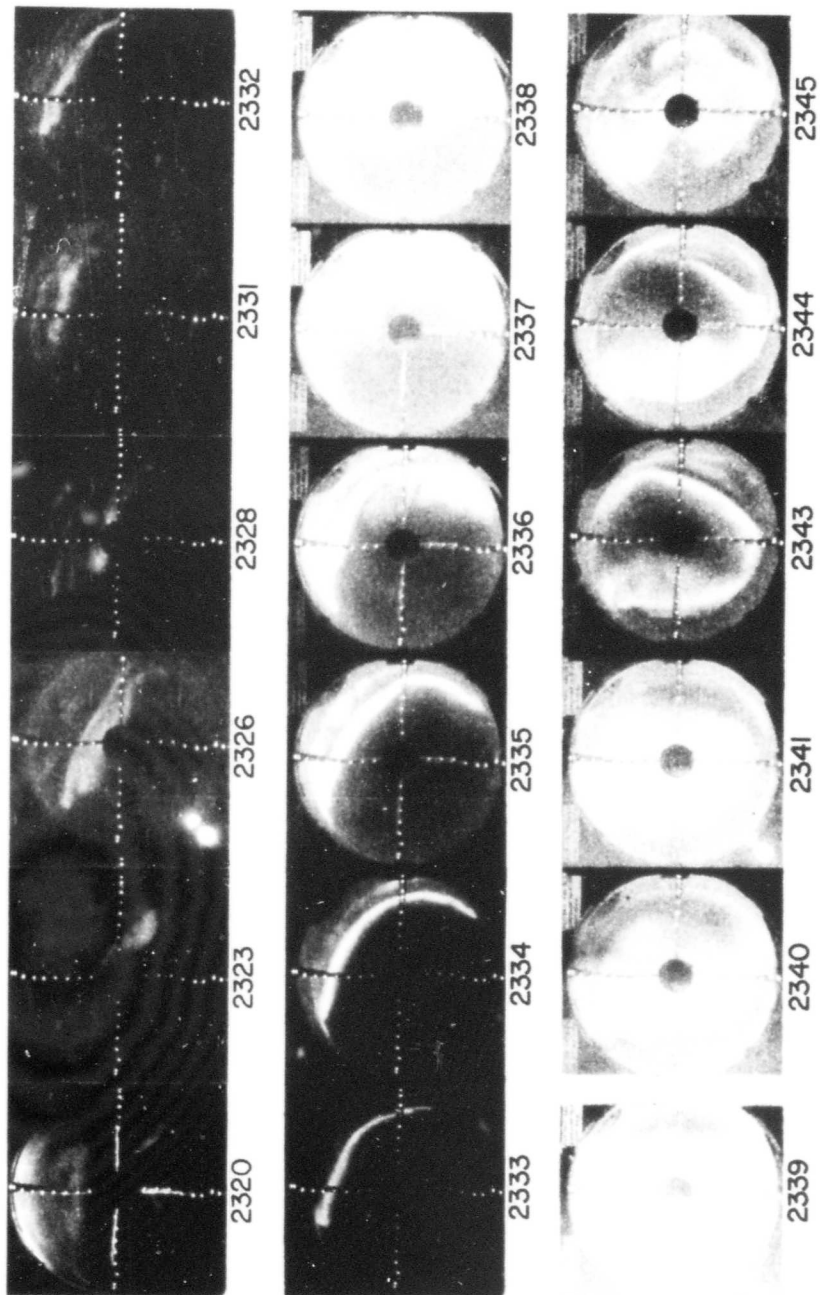Fig. 6.  MAGNETIC BAY EVENT, PLATEAU, 23 JULY 1966, 2320-2345 UT.

Fig. 7. SELECTED ALL-SKY PHOTOGRAPHS FOR FIG. 6.

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| 2338 | The aurora reaches zenith.  The noise has decreased nearly to the background level. |
| 2340 | The magnetic field reaches a minimum.  The amount of light reflected from the all-sky camera housing outside of the spherical mirror indicates that the maximum integrated light intensity occurs at this time.  The noise at 110 and 50 kHz has dropped over _3 dB below peak values at 2135.  Noise at 8 kHz is down by 7 dB, and noise at 1.5 kHz by 12 dB. |
| 2340-42 | The auroral bands are not well defined and swirl rapidly. |
| 2343 | The auroral bands are better defined as 8 kHz noise again peaks 7.5 dB over its value at 2342. |
| 2344 | A local peak appears on the magnetometer and on 1.5 kHz noise.  The latter rises to 7 dB above its value at 2342. |

3.    110 kHz Event

In Fig. 1 several bursts of noise appear on the 110 kHz channel between 0320 and 0400 after the noise activity on the three lower frequency channels has ended.  On four days of the week under study bursts of noise on 110 kHz in the absence of noise on the other bands were observed to occur after lower frequency activity had ceased for the night.  However, such bursts are not limited to the end of the night and were found throughout the active night period.  The aurora-noise plot of the burst from 0320 to 0400 on 24 July is shown in Fig. 8.  All sky photographs of the event are shown in Fig. 9.  For 25 minutes previous to 0320 there was virtually no noise above the equipment noise level and there were only small bands of fairly dim aurora moving rapidly across the sky.  A slightly brighter band in the northwest at 0308 did not affect noise.  However, a similar band at 0322 is apparently associated with noise.

A minute-by-minute description of the 110 kHz event follows:

| 0322 | A small band appears in northwest.  Noise at 110 kHz increases. |
| 0324 | Noise and auroral intensity reach a local peak. |

0326            There is a coronal burst of aurora.  Noise at
                110 kHz is at a maximum.

0326-31         Noise amplitude, auroral elevation, and auroral
                intensity all decrease.

0334            Noise at 110 kHz reaches another peak as a short
                band appears in the northeast.

0336            The short auroral band reaches maximum intensity
                at 0336.  Level of 110 kHz noise is still high,
                but it is down 2 dB from its peak.

0337-39         Auroral intensity and 110 kHz noise decrease.
                The elevation of the aurora also decreases.

0343            An auroral band appears near the northwestern
                horizon.  Noise at 110 kHz increases.

0344            Auroral intensity and 110 kHz noise peak at the
                same time.  This noise peak is 4 dB less than
                the previous peak.

0345            Both auroral intensity and 110 kHz noise have
                decreased.  Noise is down by 11 dB from the peak
                at 0344.

0347-48         Again the aurora moves toward the station and
                auroral intensity and noise increase to about
                the same level as they were at 0344.

0349            Auroral intensity reaches maximum.  Noise at
                110 kHz decreases to its background noise level.

        After 0350 the noise and aurora curves diverge as the aurora
moves overhead and the auroral intensity varies up to level 4, but drops
to zero by 0400.  The behavior of the curves between 0350 and 0400 sug-
gests that absorption has affected the 110 kHz noise.  Except for a
slight hint of activity on the 50 kHz channel at 0335, there is no
detectable activity at any of the lower frequencies.

    4.   Daytime Event

        While most hiss events and discrete auroras occur during the
magnetic night hours, occasionally bursts occur in the daytime.  An
aurora-noise plot of such a burst is shown in Fig. 10.  Photographs of

27                                    SEL-68-016
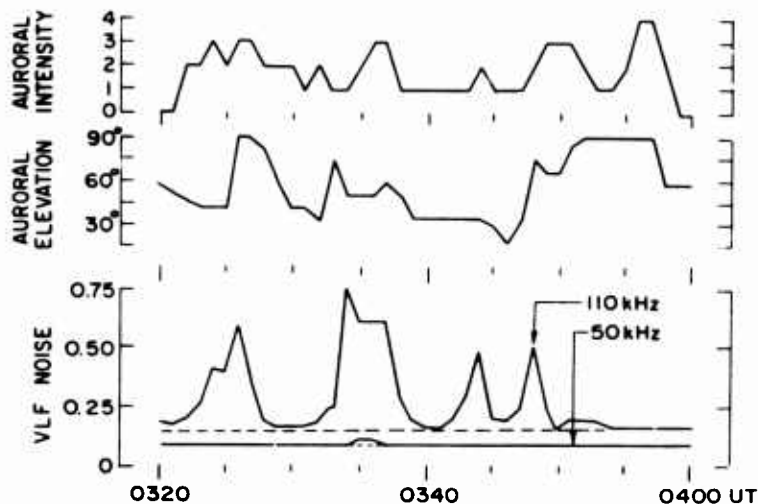
Fig. 8.    100 kHz EVENT, PLATEAU, 24 JULY 1966,
0320-0400 UT.

the aurora are shown in Fig. 11.   The bright spot in the southeast is
the moon.   The bright diffuse light along the northeast horizon is twi-
light and should be ignored.   Before 0823 there is no noise activity
above the equipment noise level and the aurora is in the form of a very
dim quiescent patch in the northeast (not discernable in Fig. 11).

        The curve of noise at 1.5 kHz has been omitted in Fig. 10
since there is no activity above the equipment noise level at this
frequency.

        In this event an auroral band and noise appear almost simul-
taneously.   Noise and aurora also fade at the same time.   A description
follows:

        0823            Noise begins to increase at all frequencies.

        0824            Noise at 8 kHz peaks.

        0825            Noise at 110 and 50 kHz peaks as the weak auro-
                        ral patch is suddenly replaced with a small band
                        in the west.
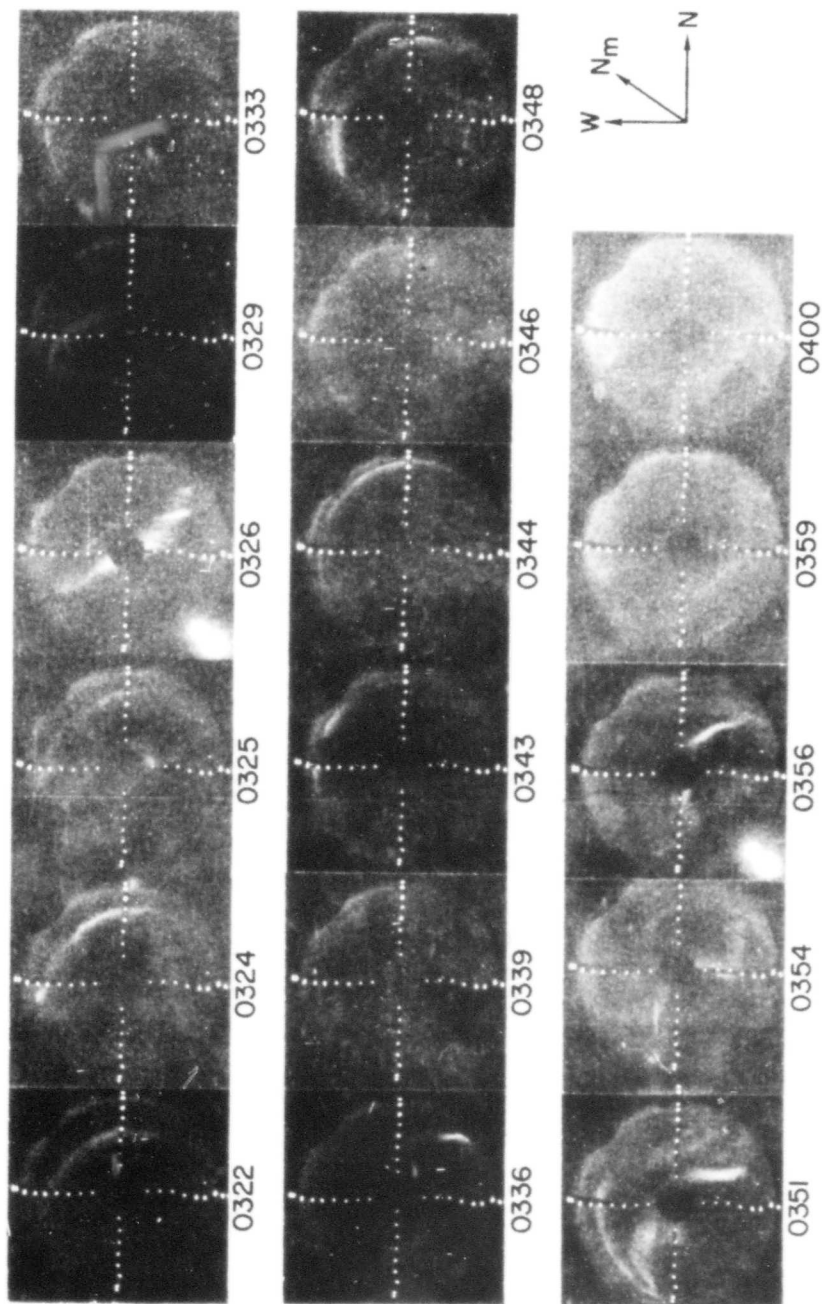
Fig. 9. SELECTED ALL-SKY PHOTOGRAPHS FOR FIG. 8.
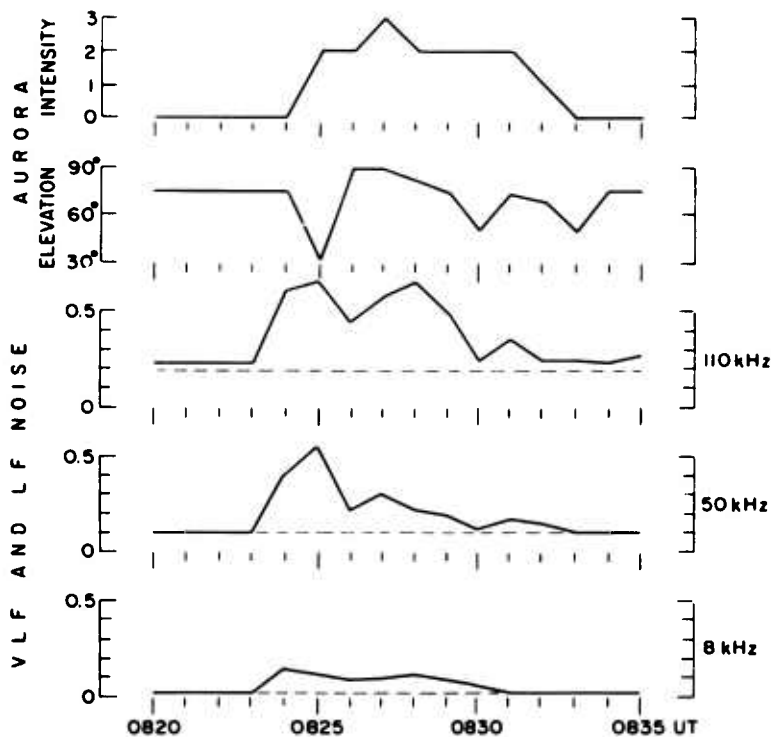
Fig. 10. DAYTIME EVENT, PLATEAU, 27 JULY 1966, 0820-0835 UT.

| | |
|---|---|
| 0826 | The patch moves quickly to zenith. The noise decreases again by 4 dB at 110 kHz, by 8 dB at 50 kHz, and by 6 dB at 8 kHz. |
| 0827 | Auroral intensity reaches a maximum. Noise again increases. |
| 0828 | Noise at 110 kHz reaches a second peak of about the same amplitude as the first peak. The aurora begins to move away. |
| 0831 | The level of noise at 110 kHz reaches another small peak 10 dB below its previous peaks. Another auroral band passes near zenith. |
| 0835 | Conditions are the same as before 0823; there is no noise activity and the only aurora is a faint patch. |
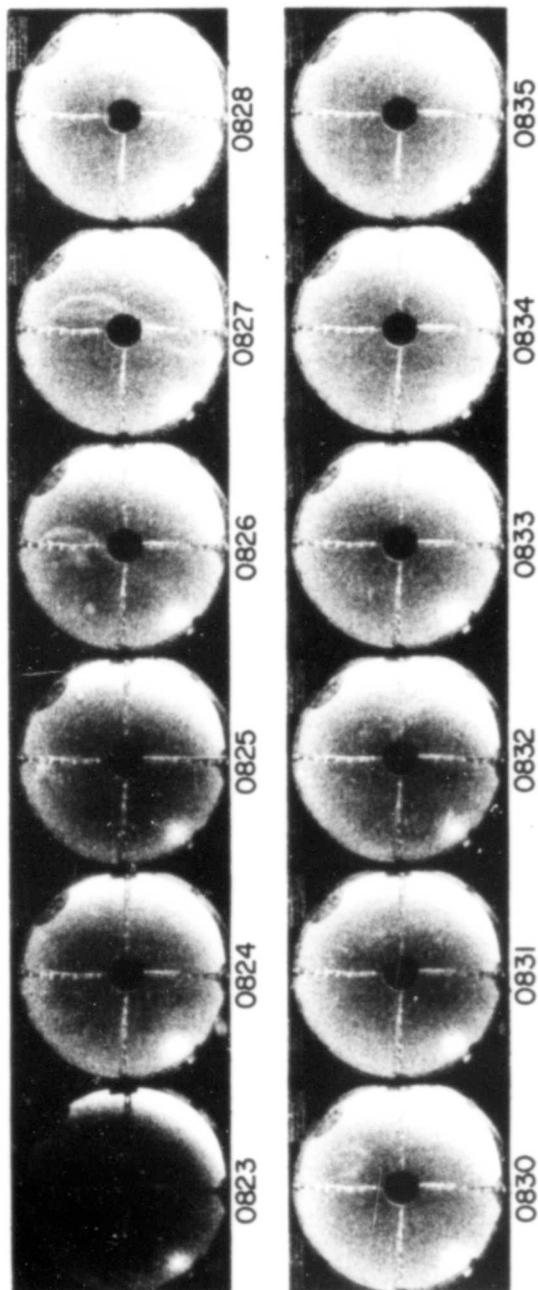
Fig. 11.  SELECTED ALL-SKY PHOTOGRAPHS FOR FIG. 10.

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## 5.    Variations in Noise Spectra

From the widely varying behavior of the different noise fre-
quencies during hiss events, it is evident that the spectral shape of
the noise must also be undergoing considerable changes.  As a rough
illustration of such changes, Fig. 12 shows noise spectra sketched on
basis of the four noise frequencies at selected intervals for an hour
during the activity previous to the first magnetic bay on July 21.  The
amplitude calibration is not consistent from one frequency to another so
that the shape of any single spectrum does not have physical significance.
The point of interest is the change of the spectrum from one minute to
the next.  All-sky photographs corresponding to the same minutes are
shown in Fig. 13.

Many of the major changes in spectral shape are reflected in
auroral changes.  While a peak on 50 kHz at 1940 has no obvious couter-
part in the aurora, a 50 kHz peak at 1952-54 coincides with the presence
of an auroral band in the northwest sky.  All frequencies rise at 2002
at the same time as an extremely bright band of aurora appears.  An
amplitude decrease in the low frequency end of the spectrum occurs at
2008 when the aurora becomes dimmer.

A description of noise and auroral activity follows:

1922        Some noise is present at all frequencies.  A
            thin band of aurora runs from north to west just
            above the horizon.

1928        The auroral band is weaker.  A second band ap-
            pears in the north.  Noise at 8 kHz had dropped
            by 7 dB.

1936        Both of the auroral bands are weaker and more
            diffuse.  Noise has decreased.

1938        Noise at 8 kHz increases.  The band nearer to
            zenith is brighter.

1940        The two bands are about equal in intensity.  A
            third weak band has appeared between the two
            bands.  Noise at 8 kHz is low but noise at 50 kHz
            rises to three-quarters full scale in two minutes.

1942        There is almost no apparent change in the aurora
            but the noise at 50 kHz has decreased by 8 dB.

| 1944 | Noise at all frequencies is low again. The aurora is weak. |
|---|---|
| 1948 | A short, bright band of aurora is in the west. Noise at 8 and 50 kHz has risen slightly. |
| 1954 | A narrow band appears on the northwestern horizon. Noise at 8 and 50 kHz rises. |
| 1958 | The aurora is more diffuse. Noise at 50 kHz decreases by 8 dB. |
| 2000 | The aurora is slightly brighter. Noise at 8 kHz is higher while there is almost no noise at 50 kHz. |
| 2002 | The auroral band is very bright. Noise at all frequencies except 100 kHz is nearly at full scale. Noise at 8 kHz rises 4 dB in two minutes. The other three bands rise from their background level to nearly full scale in two minutes. |
| 2004 | The band breaks into parallel bands, becomes still brighter, and the closer band moves toward the zenith. Noise at all frequencies is high. |
| 2006 | The band moves further toward zenith and becomes broader. Noise at 1.5 and 8 kHz decreases by about 7 dB. |
| 2008 | The band is less bright and noise at all frequencies is lower. Noise at 50 kHz has decreased by 11 dB in two minutes. |
| 2010 | The aurora is again brighter and noise intensities at 8 and 50 kHz are higher by 8 and 17 dB, respectively. |
| 2016 | The band retreats toward the horizon. A second more diffuse band appears in the northwest. Noise at 1.5 kHz is greater by 2.1 dB and noise at 50 kHz decreases 10 dB from its level at 2010. |
| 2022 | A bright diffuse band forms inside the bright band in the west. The diffuse band in the north breaks up. Noise at 1.5 kHz decreases by 10 dB, but the noise at 8 kHz remains high. |
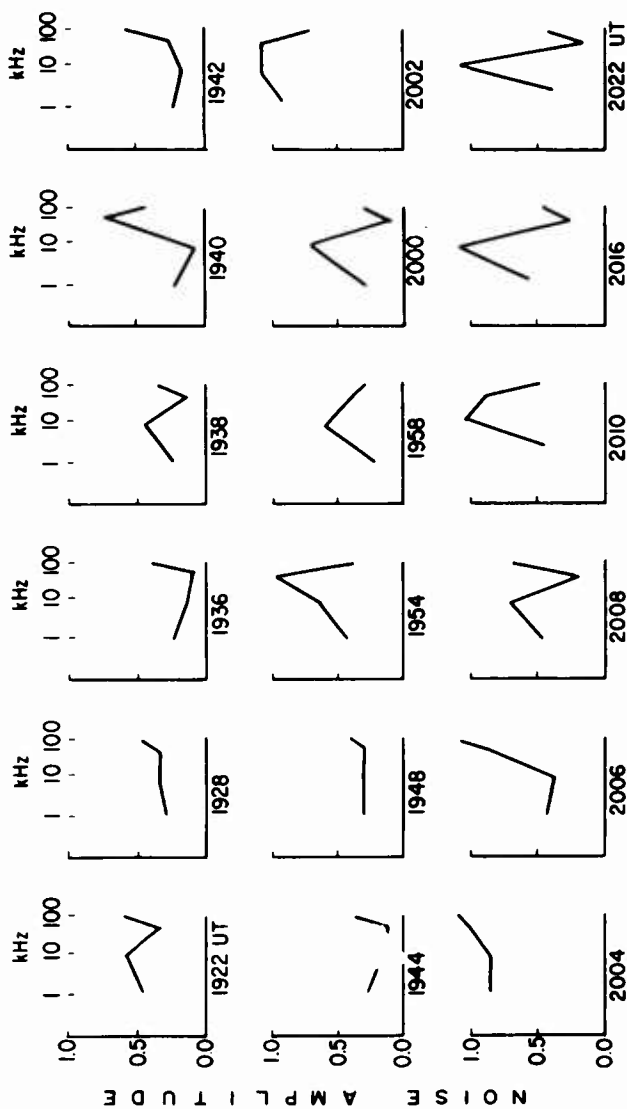
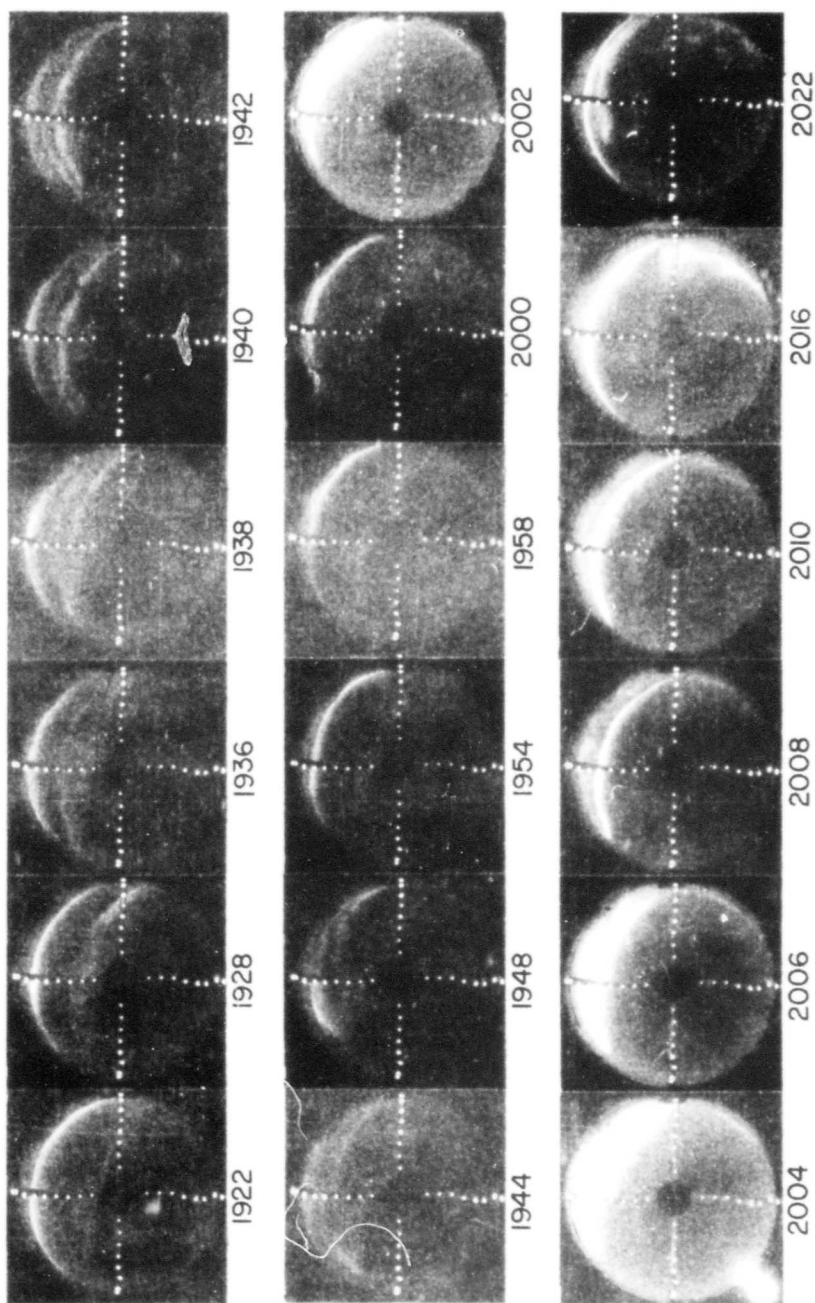Fig. 12. NOISE SPECTRA, SKETCHED ON THE BASIS OF FOUR FREQUENCIES, PLATEAU, 21 JULY 1966, 1922-2022 UT.

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Fig. 13. ALL-SKY PHOTOGRAPHS CORRESPONDING TO FIG. 12.

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### 6.   Variation of Noise with Auroral Intensity, Absorption and Auroral Elevation

Natural noise appears to be related to both auroral intensity and to various spatial characteristics of aurora such as elevation, form, and movement. Although the coded description of the aurora for each minute is primarily qualitative, a statistical relationship was found between natural noise and auroral intensity. The relationship between natural noise and auroral elevation was investigated.

The correlation of auroral intensity with natural noise was checked by plotting average noise amplitude for the week versus auroral intensity number for each frequency. Each day was divided at the main magnetic bay and the average noise computed separately before and after the bay for each auroral intensity number from 1 through 4. A main bay can generally be found, although on quiet days it may be weak while on very active days a choice between several bays must be made. The results are shown in Fig. 14. In general the average noise level is greater for higher auroral intensity, although there are exceptions to this tendency. That the correlation is imperfect is not surprising since noise also varies with spatial characteristics of aurora, the intensity numbers are subjective, and absorption frequently also varies with auroral intensity.

In Fig. 14, the average noise before the bay is always greater than the average noise after the bay for each intensity number. However, the proportion of minutes in which the aurora is bright (intensity 3 or 4) is about the same both before and after the bay (59 percent vs 57 percent). Therefore, the average intensity of the aurora is not significantly changed following the magnetic bay, but the average noise is lower for all intensities, presumably due to absorption.

The variations of natural noise with the elevation of aurora was also investigated. Many instances of increasing elevation correlating with increasing noise level were found. However, high noise levels are frequently associated with bright auroral bands regardless of elevation so that averaging noise levels for various auroral elevations over the period studied did not yield a consistent variation of average noise with elevation. However, of approximately 2200 minutes of hiss activity during the
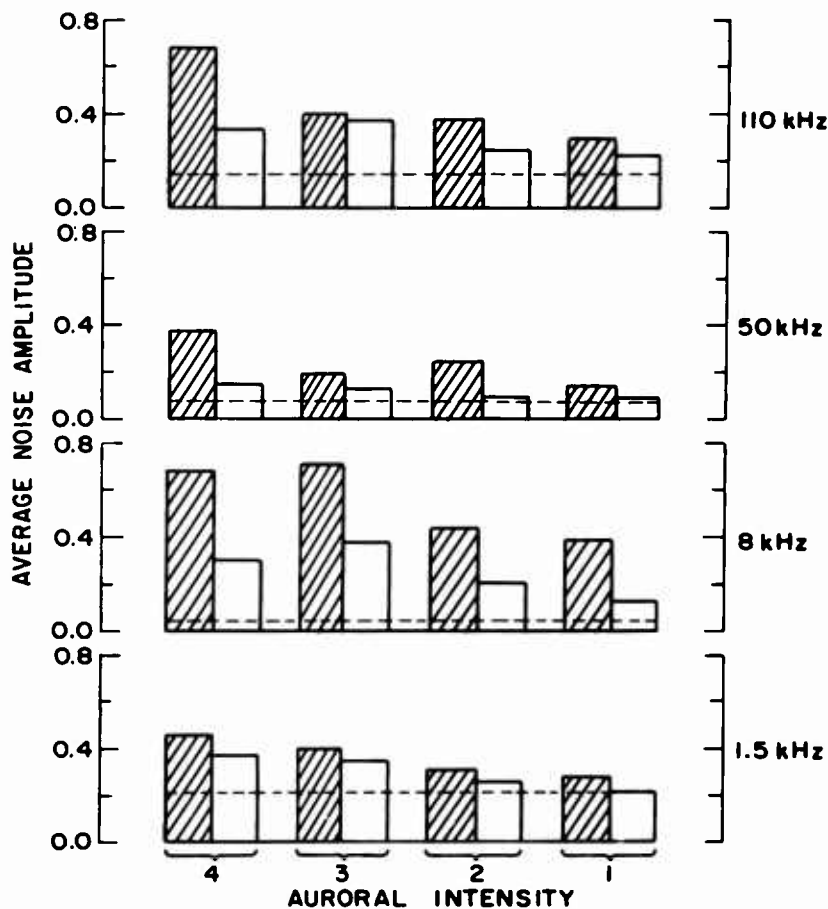
Fig. 14.   VARIATIONS OF AVERAGE NOISE WITH AURORAL
 INTENSITY BEFORE AND AFTER MAIN MAGNETIC BAY.   Shaded
 blocks represent the average noise amplitude before
 the main magnetic bay.   White blocks show the amplitude
 following the bay.   Dotted line shows approximate aver-
 age equipment noise level.

week studied, there was aurora within 45° of zenith during about 1600 minutes. Auroral forms lower in the sky existed for virtually all the remaining minutes of hiss, leaving only 13 minutes throughout the entire week when hiss existed with no aurora in the sky. Thus the noise and auroral elevation frequently appear to be related, but the relationship is complex.

## 7. Extent of Relationship between Noise and Aurora

To obtain a measure of the extent to which noise is related to aurora, the number of "major changes" in noise amplitudes which correspond to auroral changes was counted for the week under study. A "major change" in noise was arbitrarily defined as a change of 20 percent or more of full scale within twc minutes on the noise charts. Auroral changes included changes in intensity, elevation, activity or form of the aurora. An auroral change was regarded as corresponding to a major change in noise only if the auroral change definitely began at the time of the noise change. The number of major noise changes corresponding to auroral changes could then be compared to the total number of major noise changes.

Major noise changes were divided into those which appeared on all frequencies simultaneously, those only on 8 kHz, those only on 110 kHz, and other changes including those which appeared on 1.5 kHz, 50 kHz, or any two or three of the four noise frequencies. Of all the noise changes within each of these categories, the percentage of noise changes which appeared to be related to auroral phenomena was calculated using the aurora-noise plots previously made. However, the numbers scaled from the auroral photographs do not reflect certain details, such as subtle intensity changes, amount of sky covered, or appearance and disappearance of secondary bands in areas of the sky away from the visually dominant bands. Therefore, the auroral data at the times surrounding major changes in the noise were scanned for other possibly related activity and again the percentage of noise changes which coincided with auroral changes was calculated. Related changes found without referring back to the films will be denoted as "Type 1" relationships and those found by scanning the films at times near major noise changes will be denoted as "Type 2" relationships.

The results are shown in Table 2. Noise bursts most closely related to aurora are those in which all four frequencies are affected nearly simultaneously. In fact, the Type 2 relationship for "all-frequency" bursts is 100 percent, indicating that all wide band noise bursts are associated with auroral changes. Noise events appearing only on the 100 kHz channel were closely related to aurora, while of the events appearing only on the 8 kHz channel, three-fourths coincided with auroral changes identifiable from the films and less than one half coincided with auroral changes identifiable only from the aurora-noise plots. Over the week as a whole, the majority of all noise changes appear to be related in some way to aurora. Of a total of 252 major noise changes, 55 percent and 85 percent were linked to aurora by a Type 1 and Type 2 relationship, respectively.

#### Table 2

PERCENTAGES OF MAJOR NOISE CHANGES RELATED TO AURORAL CHANGES

| Frequency | Number of Major Noise Changes | Percentage changes Related to Aurora | |
|---|---|---|---|
| | | Type 1 (%) | Type 2 (%) |
| 1.5, 8, 50, 110 kHz simultaneously | 33 | 79 | 100 |
| 110 kHz only | 65 | 67 | 92 |
| 8 kHz only | 92 | 45 | 76 |
| Others | 62 | 45 | 84 |
| Any frequency or combination of frequencies | 252 | 55 | 85 |

The identification of aurora-noise associations by starting from noise changes and looking for related auroral changes yields a higher correlation than would be obtained if the process were reversed and the auroral changes were used as the starting point. Since auroral photographs contain spatial detail, it is hardly surprising that every auroral change is hot accompanied by identifiable changes in the noise since the latter is made up of the rms addition of spatially unresolved

components. On the other hand, there are occasionally large auroral bursts with virtually no VLF or LF noise. Absorption certainly accounts for at least some of this lack of correlation since auroral bursts without noise often occur after the main bay when absorption is known to be high. It is not possible to determine from the data whether the absence of noise during overhead aurora is ever a generation rather than a propagation effect.

## Chapter V

## SUMMARY AND CONCLUSION

### A.   Summary of Experimental Observations

The principal results of this observational study of the relation-
ships between aurora and noise at Plateau Station are listed below:

(1)   The midnight and noon peaks in the diurnal variations of the
      occurrence of noise at Plateau Station at 1.5 kHz and 8 Khz
      are similar in magnetic time to those previously reported for
      VLF chorus and hiss at other polar stations [Helliwell, 1955;
      Jørgensen, 1966].

(2)   The peaks in the diurnal variation of noise occurrence at
      110 kHz coincide with the peaks at 8 kHz.

(3)   The diurnal variation of aurora also exhibits the midnight
      peak.   Percent occurrence of aurora decreases more gradually
      than that of noise after magnetic midnight.

(4)   Following a simultaneous amplitude increase of noise at all
      frequencies, the aurora generally brightens immediately and
      within a few minutes moves toward the station.

(5)   When a change of the noise at one or more frequencies occurs,
      some characteristic of the visible aurora often changes
      simultaneously:

      (a)   When 8 κHz is the only active noise band, the aurora is
            frequently dim and fast moving.

      (b)   Changes in the amplitude of the noise at 110 kHz are
            statistically more closely related to auroral changes
            than are changes in the noise at 50, 8, or 1.5 kHz.

(6)   Average natural noise for all frequencies correlates positively
      with auroral intensity.

(7)   Average noise corresponding to a given auroral intensity de-
      creases following the main magnetic bay.

### B.   Discussion

The extent to which noise bursts can be matched with auroral bursts
indicates that the causes of the two phenomena are related in time.

However, the details of their spatial relationship has not been deter-
mined, although there is evidence that aurora and noise must be spatially
correlated to within a few hundred kilometers on the surface of the
earth. To be within line-of-sight of a receiving station, aurora must
be less than 1500-2500 km away at typical auroral heights. During
three-quarters of all the minutes in which hiss was present, auroral
forms were found within $45°$ of zenith. Such forms must be no more than
a few hundred kilometers away. Auroral hiss bursts recorded at ground
stations only 2000 km apart were found to coincide infrequently by Helms
and Turtle [1964]. From this observation they conclude that the gener-
ation region for hiss (or its exit point from the exosphere) must be with-
in a few hundred kilometers of the station at which it is received. The
results of Harang and Hauge [1965] are consistent with this conclusion.
Using crossed loop antennas, they find no preferred direction of arrival
for hiss bursts during auroral displays. Hiss bursts are found to con-
sist of circularly polarized waves as would be expected of waves travel-
ing in the whistler-mode. Waves of such polarization would not yield an
indicated direction on crossed loops for sources at short range (within
$45°$ of zenith). It appears safe to conclude that auroral forms and noise
sources (or exit points) coincide within a few hundred kilometers.

The finer details of the spatial relationships are still obscure.
Earlier in this report a typical sequence of events surrounding the
magnetic bay was described. As aurora moves overhead, noise decreases,
indicating increasing absorption. If absorption and aurora appear at
the same place, it follows that the noise received when the aurora is not
over the station does not come from the aurora because it would be ab-
sorbed at the source. The observed sequence of events might be explained
by a stream of auroral particles which while traveling down a line of
force generate noise at high altitudes and aurora and absorption at lower
altitudes. The noise might then spread over a larger area on the surface
of the earth than the absorption or aurora, and the noise pattern would
then be roughly in the shape of an annular ring with absorption and au-
rora at its center. The pattern might be further complicated by the fact
that it takes many minutes for the ionosphere to recover from an absorp-
tion event, whereas aurora and noise generation would be more closely

tied to the causative particle streams. Therefore, an understanding of
the spatial relationship of aurora and noise would be aided by a com-
parison of the effective areas of aurora, noise and absorption.

Although the discovery of bursts of noise at 110 kHz which are not
accompanied by noise at lower frequencies was an unexpected result, hiss
with various upper and lower cutoff frequencies has been observed at fre-
quencies below 40 kHz [Helliwell, 1965]. Thus, the "110 kHz events" are
hiss bursts whose lower cutoff frequency lies between 50 and 110 kHz, and
are therefore an extension of a familiar lower frequency phenomenon.
Since absorption, both through the ionosphere and in the earth-ionosphere
waveguide, is expected to rise with frequency, the "110 kHz events" could
be a propagation effect only if the source were much closer to the receiv-
ing station for these events than for others. Propagation effects could
not account for the occasional events which appear at 50 kHz, but not at
110 or 8 kHz. Therefore, the band limiting which produces events only at
110 kHz or, more rarely, only at 50 kHz is presumably a generation rather
than a propagation effect.


C.   Suggestions for Further Work

Further study of the relationships between natural noise and aurora
would aid in achieving a better understanding of the interactions of
auroral particle streams with the ionosphere and exosphere. Specific
goals of such further study might include better statistical data on
aurora and natural noise, more detailed knowledge of the spatial and
temporal behavior of absorption, more complete information on the spec-
tral changes in noise and the relationship of such changes to auroral
changes, and investigation of the exact time relationships between cor-
related auroral and noise events.

The amount of data which could be scanned for this paper was limited
by the time-consuming scaling required, especially of auroral photographs.
The derivation of statistical data would be facilitated by the develop-
ment of better and faster scaling techniques. By using a scanning sys-
tem or a photo-cell grid for scaling all-sky photographs, parameters
such as elevation, azimuth, intensity, percent of sky covered, and the

direction and rate of motion could be automatically scaled using a computer, leaving only the more complex forms to be recognized by an observer. Slow speed magnetic tape or digital punch tape could be used to record noise amplitude from filtered channels or a spectrum analyzer, facilitating automatic scaling of noise data. With both auroral and noise data in digital form, correlation of a wide variety of parameters could be readily carried out.

Digital data would be particularly useful in an investigation of noise and auroral elevations. These results would give more insight into the spatial relationships between aurora and noise discussed in the previous section.

Absorption obviously has a large effect upon received natural noise. Vertical riometer studies are useful in determining the timing and amount of overhead absorption. Patches of absorption could be studied in greater detail using a VLF transmitter of known strength on the ground and a calibrated satellite borne receiver. Absorption could thus be measured on a whistler-mode path between the satellite and ground and the spatial distribution of absorption patches could be compared to the position and types of auroral forms.

Better spectral information on noise, especially above the cutoff frequencies of normal broadband tape recordings (about 20 kHz at Plateau) is desirable to establish the spectral shapes of noise bursts for comparison with various types of auroral activity. Such information can be gathered using either fixed frequency filters or a spectrum analyzing device. The upper frequency limit of auroral hiss is not known; Trimpi[*] has reported aurora-associated hiss at 400 kHz at Byrd Station. Data on the frequency limits and spectra of hiss are important in checking the applicability of postulated hiss generation mechanisms.

Within the one minute time resolution of the data used in the report, some changes of aurora and noise have been found to be precisely related in time. Better time resolution of auroral events is possible using a

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[*]Personal communication.

television system [Davis, 1966]. Aurora and noise could be recorded on the same videotape from which it would be possible to make very detailed comparisons of the onsets of auroral events and noise bursts.

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